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The structure of humus and dynamic of litter decompositon on a Luvisol and a Podzol under forest

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With 10 Figures

1. Introduction

Humus is made up of litter and humic substances (SCHEFFER & ULRICH, 1960). It is a product of microbial and faunal decomposition processes, which are dependent on the vegetation stock and the abiotic conditions (MITCHELL & NAKAS, 1986).

In beech forests different soil animal groups are to be found in the soils with moder (BECK, 1989) than in the soils with mull (SCHAEFER, 1982; 1989). A larger amount of saprophage microfauna is to be found in mull than in moder (THIELE, 1968). The composition of the soil animal community and its biotical activity influences the decomposition and humification of the litter and the development of the humus (BAL, 1970).

Clear differences exist between Luvisols and Podzols in Schleswig-Holstein with regard to the nutrient supply (BLUME *et al.*, 1986) and the composition of the soil fauna (IRMLER & HEYDEMANN, 1988; 1989). In 1986 and 1987, therefore, a beech-oak mixed forest on Luvisol in Ostholstein and a spruce forest on Podzol in the Holsteinische Vorgeest were investigated. The aim of this research was to determine both, humus morphology and seasonal dynamic as consequences of the different nutrient supplies from the soils, the composition of the soil fauna, and the plant community.

2. Method and sites

2.1. Methods

The morphology of the soils was described according toe BREWER & SLEEMAN (1960), BABEL (1965), SCHLICHTING & BLUME (1966) and ANONYMOUS (1988: AK Standortskartierung).

In order to determine the litter and humus substance groups air dried soil samples were analysed using the following wet chemical method according to SCHLICHTING & BLUME (1966): The litter substance were extracted using acid and organic solvents. The humic substances were extracted using NaOH and H_2SO_4 alternately. Carbon and nitrogen were determined by dry combustion in the CHN-analyser (Fa. Heraeus). For a more detailed description of the analyses see BEYER (1989).

The temperature in the L-horizon (see Sect. 2.2.2.1) was permanently measured with temperature sensors. The average values were calculated from 2 hours data. The thermal supply was calculated using the exponential average temperature according to PALLMANN *et al.* (1940) with three parallels over 6 and 12 weeks respectively on volume, air volume, mineral volume, humus volume, horizon thickness and thermal capacity derived from known specific heat were used in order to calculate the thermal supply.

The determination of the water tension was carried out fortnightly at depths of 20 and 50 cm using pressure gauge tensiometers (3 replicates). Precipitation was recorded every two weeks at a height of 1 m from 5 parallels. The thickness of the L-horizon of 10 parallels was measured every 6 weeks. The litter fall was estimated quantitatively every month from an area of 1 m^2 (9 replicates). In order to detemine soil respiration the output of CO_2 was measured from adsorption by NaOH over 24 hours using Lundegårdh cylinders at 2–6 week intervals with 5 parallels (ANDERSON, 1982).

The soil fauna was recorded with three parallels in three layers: The soil surface and soil vegetation, the litter layer, and the topsoil. The fauna from the soil surface and the soil vegetation was caught

using a vacuum trap with an area of 0.1 m^2. In the litter layer samples the fauna was selected by hand from an area of 0.1 m^2 and then extracted in the Kempson-Tullgren apparatus. Furthermore the fauna from the topsoil (0.25 dm^2 area, 4 cm depth) was extracted in the Kempson-Tullgren apparatus. The litter decomposition was measured using net bags. The proportion of different animal groups that play a part in primary decomposition can be estimated using the varying mesh sizes (0.5 cm, 250 µm, 21 µm) of the net bags. In the spruce forest the 0.5 cm mesh size had to be done without. This was because of the small size of the needles which would have fallen through the holes. The net bags were filled with 8 g autumnal leaf litter in January 1986. The determination of dry mass was carried out on three replicates at two month intervals. The rate of decomposition was calculated according to OLSON (1963) using the following formula: $X/X_0 = e^{ct}$ (X = remaining mass after the time period t, X_0 = initial mass, C = constant). The 95% decomposition rate can be calculated using 3/C.

2.2. Sites

2.2.1. General description

Two typical forest soils in Schleswig-Holstein were investigated: A Luvisol in Siggen near Oldenburg in Ostholstein and a Podzol in the Segeberger Forst in the Holsteinische Vorgeest.

A moderately wet beech-oak mixed forest (Melico-Fagetum) is to be found on a Orthic Luvisol (fig. 1). The tree stock is about 150 years old. The Luvisol from Weichselian boulder marl above fluvioglacial sand (12 m above sea level, ground water 4–6 m below ground level) is poor in bases. The acidification is very advanced, as is the loss of bases. The soil is well rooted and aired thoroughly. The topsoil is poor in nutrients (tab. 1) but the medium to large nutrient reserve (BLUME *et al.*, 1986) result in highly productive beech trees, whose roots reach boulder marl containing carbonate in the subsoil (tab. 1).

The spruce forest (about 100 years old) stocks on a Haplic Podzol from Weichselian sandurs with raw humus (29 m above sea level, ground water 2–4 m below ground level). The subsoil is gleyed. Old pine (*Pinus silvestris* L.) trees are also to be found and the forest has a flat rooting. The topsoil is very acidic and poor in nutrients (tab. 2). The soil vegetation consists of a typical **Betulo-Quercetum** flora, which accompanies the trees (fig. 2).

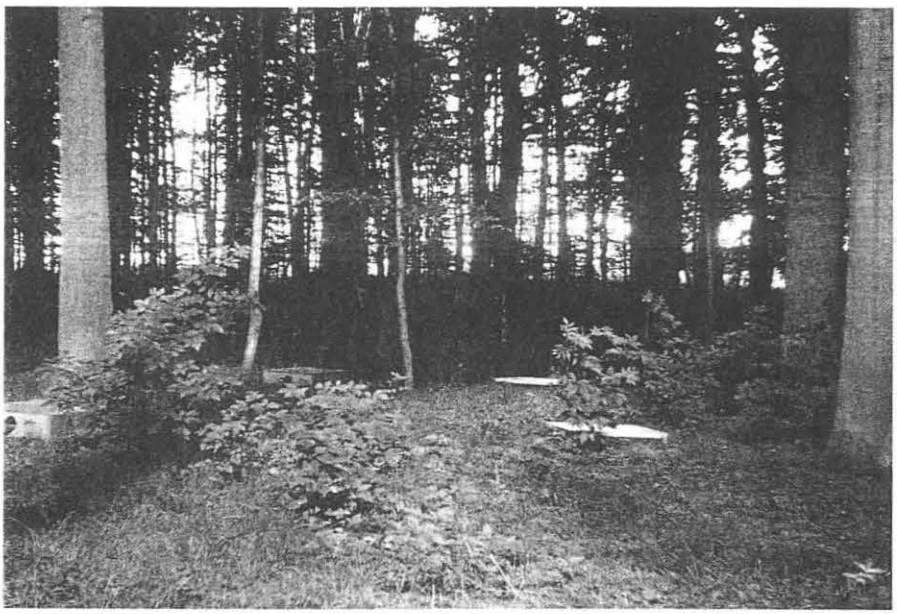


Fig. 1. Beech-oak mixed forest on Luvisol in Siggen.

Tabelle 1. Characteristics of a Luvisol under beech/oak in Siggen.

Hor.	depth	bulk density	tex-ture	*p*H	CEC	H + Al	V	Carb.	C_{org}	N_t	C/N
	cm	g/cm³		$CaCl_2$	meq/kg		%	%	%	%	
L	5.5–3.5	0.05		4.2					46.2	1.33	35
Of	3.5–1.5	0.2		4.0					40.8	1.67	24
Oh	1.5–0.0	0.21		3.6					20.4	1.22	17
Ah	– 11	1.10	S14	3.5	172	61	13	0.0	2.1	0.20	11
Alv	– 47	1.62	Ls3	3.8	149	96	18	0.0	0.7	0.10	7
Bvt	– 91	1.67	Lts	4.3	158	23	63	0.0	0.3	0.04	8
BtC	–117	1.71	Lts	7.3	166	2	98	6.7	0.02	0.03	6
Ccv	–182	1.74	Ls3	7.4	148	0	100	16.1	0.1	0.02	5
IIC	–200	1.69	gmS			n.d.		18.0		n.d.	

CEC at *p*H 8.2 according to MEHLICH, organic Carbon (C_{org}) by dry combustion, total nitrogen (N_t) according to KJEHLDAHL, carbonates (Carb.) according to SCHEIBLER, V: base-saturation percentage in % of CEC, n.d.: not determined.

Tabelle 2. Characteristics of a Podzol under spruce in the Segeberger Forst.

Hor.	depth	bulk density	tex-ture	*p*H	CEC	H + Al	V	C_{org}	N_t	C/N
	cm	g/cm³		$CaCl_2$	meq/kg		%	%	%	
L	15– 12	0.03		3.5	350	266	24	50.8	1.45	41
Of	12– 7	0.16		3.0	1008	885	12	45.5	1.65	28
Oh	7– 0	0.21		2.6	1142	1032	10	35.2	1.42	25
Aeh	0– 10	0.81	fmS	2.7	298	266	11	7.6	0.46	16
Ahe	– 20	1.54	fmS	3.1	17	13	25	1.3	0.05	25
Bh	– 25	1.37	fmS	3.1	289	279	3	8.0	0.23	35
Bhs	– 30	1.37	fmS	4.0	143	141	1	2.4	0.09	26
CBvs	– 70	1.59	fmS	4.5	267	26	3	1.0	0.03	40
GCv	–160	1.59	fmS	4.7	14	13	6	0.1	0.01	10

CEC at *p*H 8.2 according to MEHLICH, Organic Carbon (C_{org}) by dry combustion, total nitrogen (N_t) according to KJEHLDAHL, V: base-saturation percentage in % of CEC.

Both sites differ very much in their climate as well as in their soil characteristics and vegetation. The beech-oak mixed forest on Luvisol near Siggen has a continental climate with low precipitation, whereas the climate in the spruce forest on Podzol is more like an atlantic one, with high precipitation in summer.

2.2.2. Detailed description of the horizons

2.2.2.1. Morphology

The morphology of both soils was described in autumn 1986. The strength of the horizon (cm) is in brackets.

Luvisol

L (5.5–3.5): **Litter** which contains 50% of each of the following; whole twigs and wavy, nibbled leaves and leaf pieces. The leaf surfaces are covered with Collembola faeces; the wood pith is filled with faeces particles. 10YR2/1–10YR6/3. The layers run smoothly into one another.

Of (3.5–1.5): **Litter humus** which contains 20% fibrous twigs and skeletal leaf pieces; it is well rooted. The leaf pieces and the faeces pellets are stored in alternate layers; Enchytraeidae and Oribatei faeces with tissue and small mineral particles are to be found here; hardly any Collembola faeces are present. 7.5. YR3/2–10YR8/6. The layers run smoothly into one another.

Fig. 2. Spruce forest on Podzol in the Segeberger Forst.

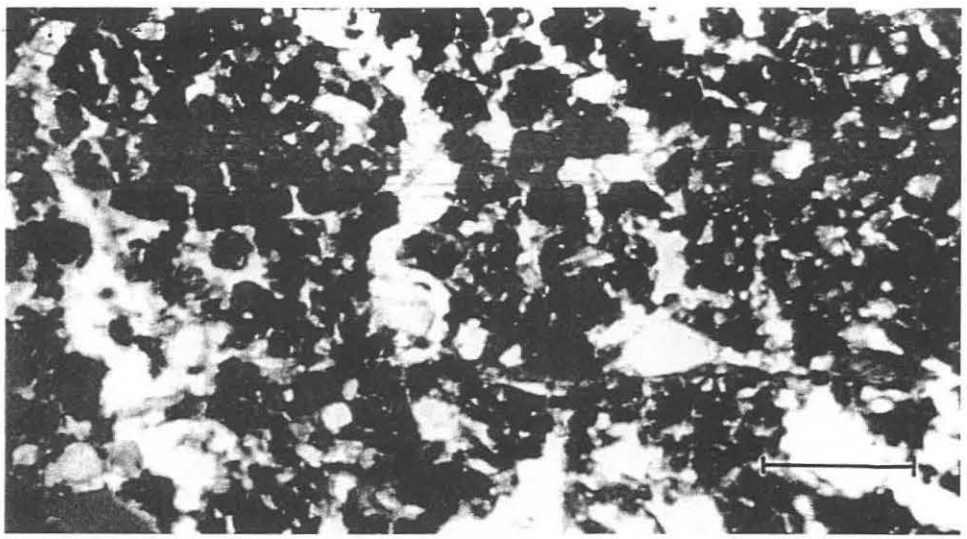


Fig. 3. Enchytraeidae faeces (fine crumbs) in the Oh/Ah-horizon of a Luvisol (scale 1 cm).

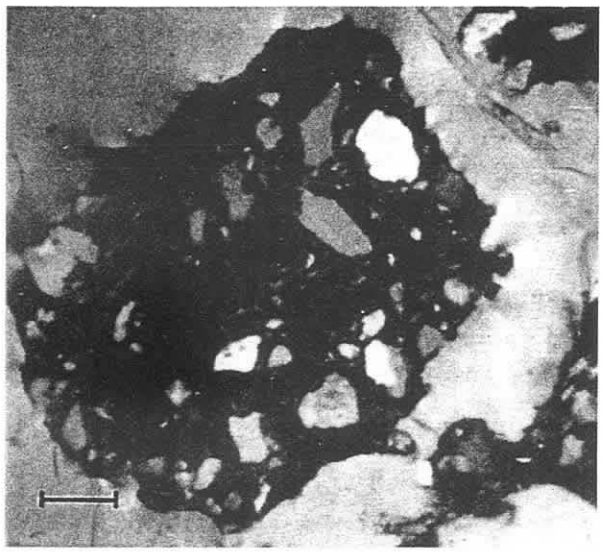


Fig. 4. Earthworm faeces (crumbs) in the Ah-horizon of a Luvisol (scale 100 μm).

Oh (1.5 – 0.0): **Moder humus** which contains compact fine humus and mineral particles; plant tissue is well decomposed and humified; it is moderately rooted and root felt is to be found; Oribatei faeces, an increased amount of Enchytraeidae faeces, and worm faeces are also present. 10YR2/1 – 10YR2/2. The layers run smoothly into one another.

Ah (0 – 11): **Worm humus** which is slightly bleached; the remains of litter are less humified, and there are tunnels with Oh and Of material here; is has a fine coagulated to crumb structure; it is rooted moderately. It has an intertextic to agglomeratic structure with plasmic structure; Echytraeidae faeces are to be mainly found, as are hollow spaces with worm faeces. 10YR2/2 – 10YR4/2. The layers run smoothly into another.

Earthworms and mice cause intensive bioturbation in Luvisol. The Enchytraeidae, in particular, participate in the decomposition of litter. They cause the characteristic fine coagulated structure (fig. 3), whereas earthworm activity results in the formation of crumbs (fig. 4). The largest part of the litter substances are incorporated and broken down within a year, so that the layer remains thin. Each of the horizons is to be found the whole year round, so that a Moder exists which is poor in fine humus.

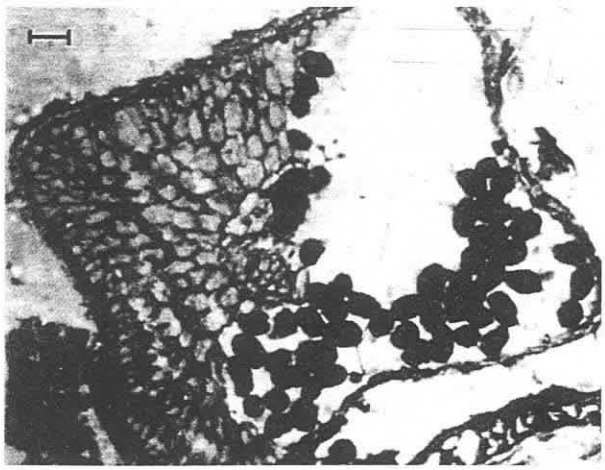


Fig. 5. Cross-sectional view of a needle with Oribatei faeces (scale 100 μm).

Haplic Podzol

L (15–12); **Litter** containing broken, stained spruce and pine needles, twigs and fruit bodies. 10YR5/6. The layers run smoothly into one another.

Of (12–7), **Litter humus** containing 40% broken, nibbled spruce needles and a few whole twigs; 30% humic substance with a root complex which is stored in layers. The plant tissue is brown and encrusted with humus. Oribatei faeces are to be found inside the needles, as are Collembola faeces when the epidermis bursts; Diptera faeces are present between the litter remains. 5YR3/2. There is a marked difference between the layers.

Oh (7–0): **Moder humus** containing 10% nibbled remains of needles; 90% compact humic substances which are stored in layers and which are felted; it is well rooted. Plant tissue is well humified. An increase in Oribatei faeces is also to be seen her (see Of): Tipulidae faeces, Enchytraeidae faeces and Diptera faeces are also present. 5YR3/3. There is a marked difference between the layers.

Aeh (0–10): **Arthropoda humus** containing hardly any vegetation remains, it has a fine coagulated structure, it is moderately rooted and has an agglomeratic to intertextic structure; opaque humus (20–30% of area) with small mineral particles (30 µm) is present. 5YR2.5/1. The layers run smoothly into one another.

The humus layer makes up the soil fauna's main living space in Podzol. Oribatei (fig. 5) dominate. Large soil animals are absent to a large extent (there are no crumbs in the Aeh horizon) or do not migrate in a vertical direction like the Tipulidae larvae. This means that hardly any mixing takes place, which in turn leads to a marked delimitation of the single horizons. The breakdown of litter substances is delayed, so that a thick layer of mor, which is rich in fine humus, is formed.

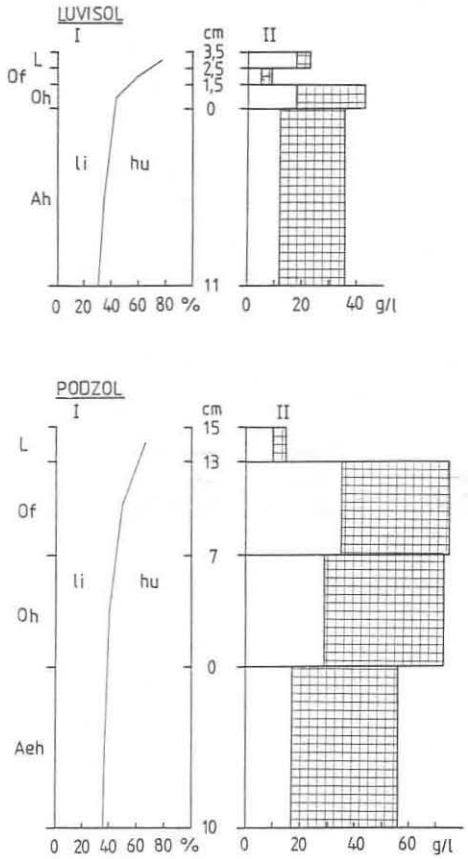


Fig. 6. Litter (li, blank) and Humic substances (hu, lined) in a Luvisol under beech/oak and a Podzol under spruce (Litter: Σ fats, proteins, polysaccharides and lignins; Humic substances: Σ fulvic acids, humic acids and humins; I: in % organic carbon, s. tab. 1+2, II in g/l soil volume).

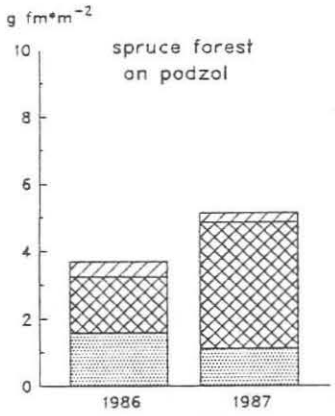
2.2.2.2. Chemistry of the humus

The distribution of the litter and humic substances in the profiles can be seen in fig. 6. The amount of litter decreases with depth and correspondingly the humic substances increase in the soil. The ratio of litter-C and humic substances-C is the same in both soils (fig. 6). Clear differences arise with regard to soil volume. The accumulation of humus caused by deficient decomposition is reflected in the Podzol by the significant role of the humus layer as carbon pool. In Luvisol on the other hand the Ah-horizon determines the composition of the humus. This layer becomes less significant, because of the continual bioturbation (Compare Sect. 2.2.2.1.).

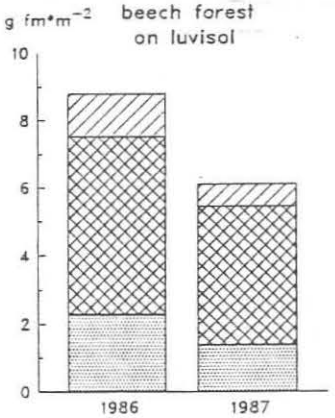
3. Results

3.1. Soil fauna

In the two years, in which the investigations took place, the beech-oak mixed forest on Luvisol had a higher biomass of soil animals than the spruce forest on Podzol (fig. 7). In both forests there were large fluctuations in the development of the soil animals between the two years. In 1987, in contrast to the previous year, the beech-oak mixed forest had only slightly higher biomass values than the spruce forest. The Tipulidae larvae in particular contribute to the yearly fluctuations. In 1987 the Tipulidae population decreased considera-



animal group	mg dm*m⁻² 1986	1987
Collembola	74	57
Oribatei	135	260
Lumbricidae	36	12
Enchytraeidae	25	4
Diptera larv.	3	22
Tiplulidae larv.	22	284
Gastropoda		8



vegetation and soil surface
litter layer
soil layer (5 cm)

animal group	mg dm*m⁻² 1986	1987
Collembola	60	64
Oribatei	55	140
Lumbricidae	166	204
Enchytraeidae	113	34
Diptera larv.	6	11
Tiplulidae larv.	84	32
Isopoda	67	88
Gastropoda	2170	444

Fig. 7. Biomass distribution of soil fauna on three layers: soil surface incl. soil vegetation, litter layer, and mineral Ah-horizon (depth: 5 cm) and the composition of the most important soil animal groups.

bly in the beech-oak mixed forest, whereas it was able to develop especially well in the spruce forest.

In the beech-oak mixed forest the biomass of soil animals is mainly found in the humus layer (fig. 7). On the other hand in the soil horizon below the humus layer the difference between the two forests is small. Some groups of saprophage soil animals are absent in the spruce forest on Podzol, because of the low *p*H value. This applies to snails (Gastropoda), millipedes (Diploda) and woodlice (Isopoda) in particular. Furthermore earthworms, such as *Lumbricus terrestris*, which dig to great depths are to be found in the beech forest on Luvisol. These worms however are not present in the spruce forest on Podzol. The most important soil animals in the spruce forest are the Oribatei, which make up the largest biomass without large fluctuations between the two years.

3.2. Annual dynamic of abiotic conditions and biotic activity

The annual dynamic in the forests is characterised by the time of the litter fall and by the annual thermal supply. The soil surface has a lower temperature in the beech-oak mixed forest than in the spruce forest (fig. 8 & 9). The thermal supply, however, is almost the same

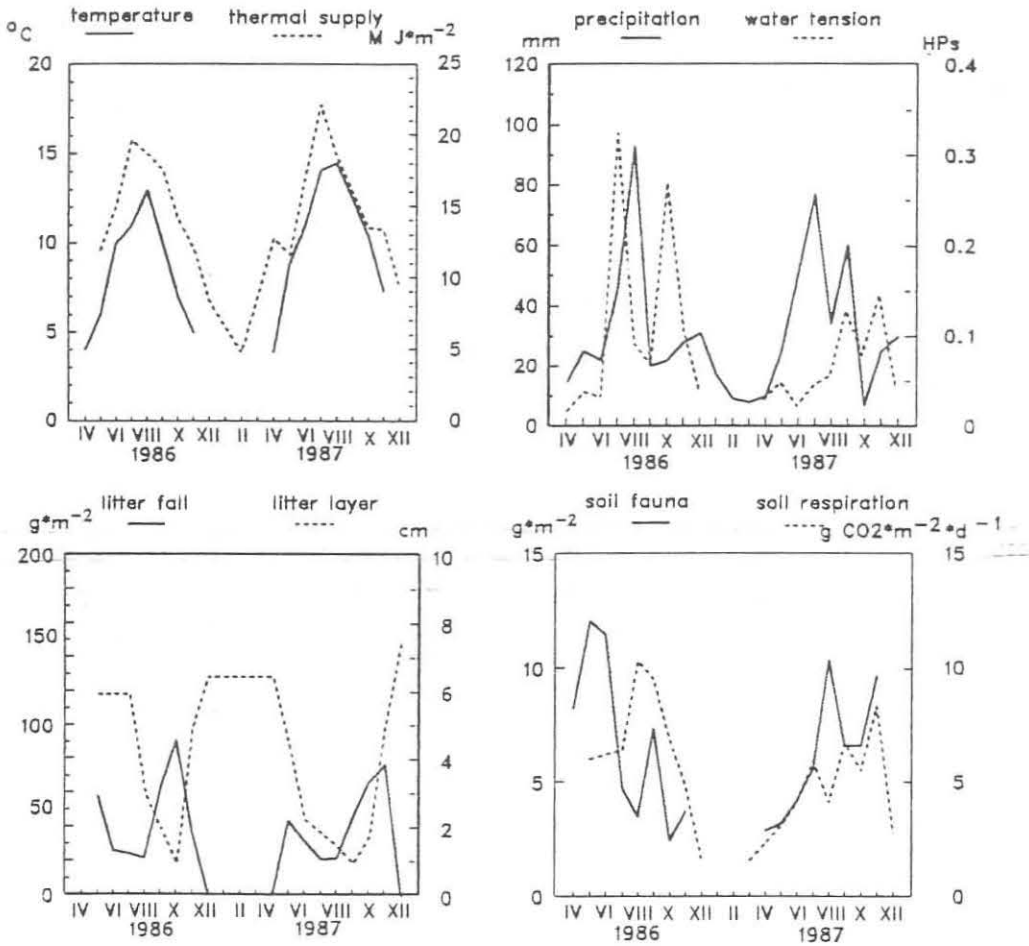


Fig. 8. Seasonal dynamic of selected environmental and soil biotical parameters of a Luvisol under beech/oak in Siggen, östliches Hügelland, Northwest-Germany.

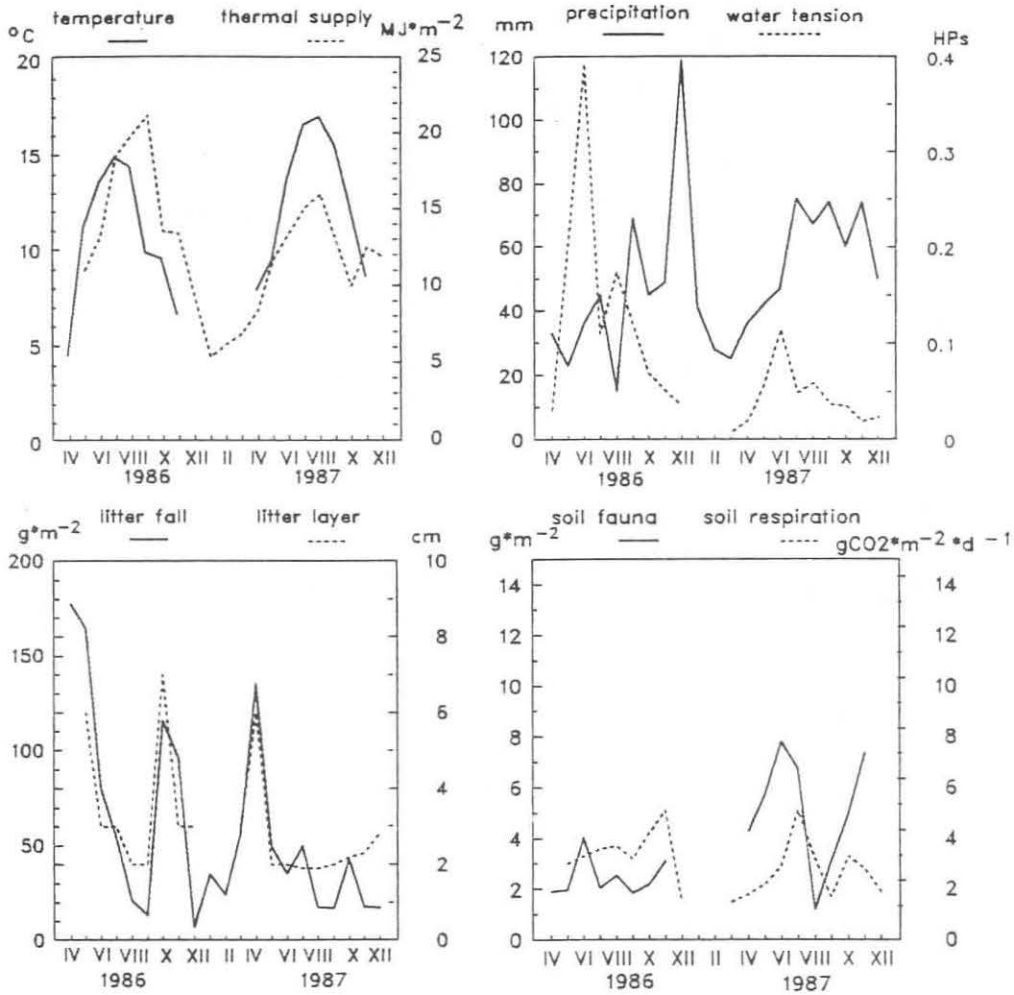


Fig. 9. Seasonal dynamic of selected environmental and soil biotical parameters of a Podzol in the Segeberger Forst, Geest, Northwest-Germany.

or even higher than in spruce forest. This can be explained by the higher thermal capacity of the loamy soil.

Precipitation in the stock varied a great deal between the two investigated years. In 1986 there was a relatively dry summer with little, though heavy rainfall in August. The water tension was correspondingly high. The beech forest remained dry in late summer and autumn, whereas a lot of rain fell in the spruce forest in autumn and which led to a decrease in the soil water tension.

In the deciduous forest the litter fall peaked in spring and autumn during the annual cycle. On the other hand there was no clear annual cycle to be observed in the spruce forest. The layer of litter on the ground correlates with the litter fall. In beech forest the L horizon clearly became thicker after the autumnal litter fall, then in the following summer it fell to the same level as in the previous summer. The thickness of the layer horizon runs parallel to the irregular litter fall from the trees in the spruce forest. The thickness of the layer is so closely related to the litter fall that here, above all, settling has to have a greater influence on the layer thickness than the decomposition process.

The annual distribution of the soil fauna results in a maximum amount of biomass in spring and autumn at both sites and therefore also in a high correlation with the annual dynamic of the litter fall. The annual cycle of the soil fauna can be modified by climatic changes. For example in 1986 a reduction in the soil fauna due to the very dry summer was recorded in the beech forest, which could only be compensated for the following year. The high level of moisture in 1987 led to an increase in the biomass of soil fauna in the spruce forest as well. During the year the soil respiration and the biomass development of the soil fauna do not run parallel to one another. The microbial activity is hindered by the low temperatures in the cold months in particular. In spring, at a time when the amount of soil fauna is at its largest, the soil respiration is still low. The highest soil respiration rates were only reached in late summer to early autumn. Superordinate climatic influences affect the microbial activity and soil fauna as well. This becomes clear when the corresponding decreases and increases in the soil fauna and soil respiration in the beech forest from 1986 to 1987 are looked at.

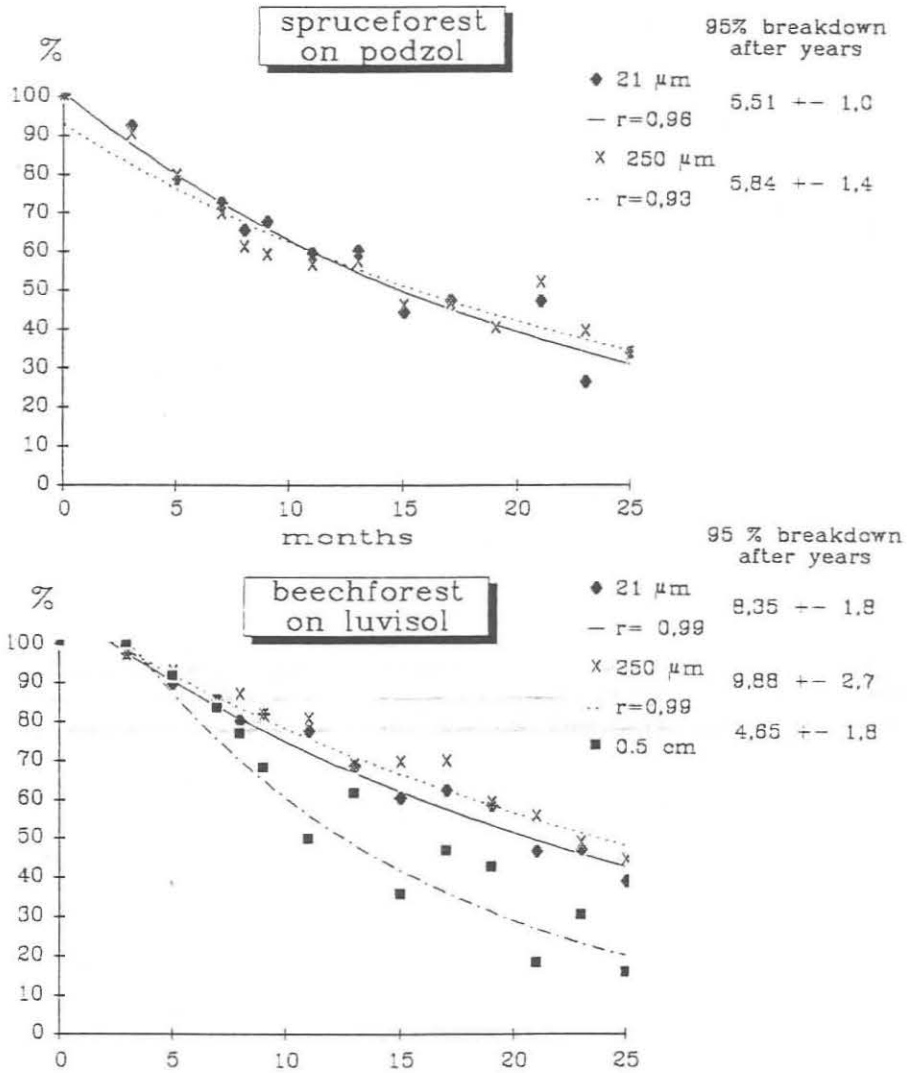


Fig. 10. Breakdown of litter (%) in the beech-oak mixed forest on Luvisol and a spuce forest on Podzol and time of 95% disappearance (standard deviation in brackets).

3.3. Breakdown of litter

At a mesh size of 21 µm bacteria, fungi and microfauna were shown to take part in decomposition. In addition to these, mesofauna at a mesh of 250 µm and macrofauna at a mesh size of 0.5 cm were also shown to participate in decomposition. In both soils there is no increase to be seen in the decomposition due to the mesofauna (fig. 10). In fact a slight reduction can be ascertained. This can probably be put down to the large amount of fungi and bacteria consumers among the mesofauna. The contribution of the macrofauna to the litter decomposition begins already in autumn.

In the spruce forest the net bags with mesh sizes of 21 µm and 250 µm show that a quicker rate of decomposition appeared to take place than in the beech forest. A difference between the two types of net bag in both forests cannot be determined.

4. Discussion and interpretation

The structure and dynamic of litter is definitely influenced by the composition of the soil fauna (THIELE, 1968, BAL, 1970; HOLE, 1981; BECK, 1987). Bioturbation by earthworms and mice causes features which characterise the profile (BAUCHHENSS, 1982). This can be observed in the Luvisol under the beech-oak mixed forest.

In moder the decomposition performance of the soil fauna is about 25% (BECK, 1989). This should be much higher in mull (SCHAEFER, 1989; HERLITZIUS & HERLITZIUS, 1977) and should clearly exceed that of the microorganisms (STACHURSKI & ZIMKA, 1976). Mesofauna, diptera larvae and fungi are important with regard to the development of moder humus and the breakdown of needle litter (SCHÖNBORN & DUMPERT, 1986; PONGE, 1988; BECK, 1989).

In the beech-oak mixed forest only the pigments are decomposed after the leaf fall in the period from October to December. In the litter layer the further decomposition is retarded by the epidermis, which protects against microbial attacks (ZACHARIAE, 1965).

With increasing depth and moisture the soil fauna becomes more active. The cellulose no longer protects against decomposition. The cell destruction causes the colonisation of myxobacteris, which decompose polysaccharides (KÖGEL, 1987). Humic substances are transferred from the Ah to the O horizon by bioturbation (BLUME, 1965).

Particularly the better supply of nutrients enables the formation of a more diverse soil fauna. In the nutrient poor spruce forest the macrofauna in the soil is almost completely absent and in contrast the presence of mesofauna is very marked. The macrofauna, in particular the large groups of saprophage animals, play a large part in the breakdown of litter in the beech-oak mixed forest. Soil respiration rates are similar to those reached in agricultural soils (BEYER, 1989). Litter and humic substances are to be mainly found in the mineral horizon, because the soil fauna transfers them to the Ah-horizon. Bioturbation and breakdown of litter, however, have decreased in the past few years. The F-mull has changed to moder, which is poor in fine humus (BEYER, *et al.*, 1991).

Bioturbation hardly takes place at all in the Podzol under spruce forest. This is confirmed by the clear expression of the different humus horizons and their very compact storage without mineral particles. The needles are broken up by Collembola and Diptera. The decomposition is supported by Oribatei, which live in the interior of the needles. Besides lignin and cellulose, hemicellulose and pectin in particular are removed from the secondary walls of the lignified cells by enzymes, without changing the tissue structure. This causes a reduction in the litter substances in the O-horizons. Fewer earthworms were observed here than in the Luvisol. This can be explained by low nutrient status of the soil substrate and the very low *p*H value. Therefore, bioturbation by Lumbricidae is strongly reduced and hardly any litter particles are to be found in the Aeh horizon. The soil fauna is found in the humus layer because the toxicity of aluminium is reduced by complexation in organometallic chelates. As a result of the reduced activity of organisms, the clearly defined raw humus has developed.

In contrast to the spruce forest on Podzol the beech-oak mixed forest on Luvisol appears to be temporarily under water stress, owing to its continental location. Besides the *p*H value and the nitrogen content of the litter, the soil moisture is important for decomposition (HOWARD & HOWARD, 1980).

Whereas in the Luvisol the soil acidification is only just beginning, and has not yet characterised the profile, the Podzol has already reached the end of the possible buffer areas. According to SCHWERTMAN *et al.* (1987) iron oxides and iron hydroxides can be already found in the buffer area at *p*H 2.7. The *p*H of the soil solution fluctuates just above *p*H 3 and the Al^{3+} concentration (PETERS, 1990) is clearly above the toxicity level of 1000 ppm (ULRICH, 1980) where a higher complexation in the form of chelate limits the toxicity (BEYER, 1989).

6. Zusammenfassung

Humusstruktur und Dynamik der Streuzersetzung einer Parabraunerde und eines Podsols unter Wald

In einen Buchen-Eichen-Mischwald auf lehmiger Parabraunerde und einem Fichtenwald auf sandigem Podsol in Schleswig-Holsteins wurde die Genese der Humusform in Abhängigkeit von der Bodentiergemeinschaft untersucht. Auf der Parabraunerde entwickelte sich ein feinhumusarmer Moder, in dem die saprophage Makrofauna einen großen Anteil am Abbau der Streu hatte. Auf dem Eisen-Humus-Podsol entstand ein feinhumusreicher Rohhumus, der durch die Tätigkeit der Oribatiden und Dipterenlarven geprägt wurde. Diese unterschiedliche Zusammensetzung der Bodenfauna wird auch bei der Analyse der Fraßspuren in den verschiedenen Auflage- und Bodenhorizonten sichtbar. In der durch kontinentales Klima beeinflußten Parabraunerde kann die Abbauleistung durch Trokkenstress beeinträchtigt werden. Im Podsol bestimmte dagegen die geringe Nährstoffversorgung die Abbauvorgänge.

7. Acknowledgement

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BEYER, L., & U. IRMLER, 1991. The structure of humus and dynamic of litter decomposition on a Luvisol and a Podzol under forest. Pedobiologia **35**, 368–380.

In beech-oak mixed forest on a loamy Orthic Luvisol and a spruce forest on a sandy Haplic Podzol in Schleswig-Holstein the genesis of humus, with regard to dependency on soil animal communities was investigated. A moder, which was poor in fine humus developed on the Luvisol, in which the saprophage macrofauna carried out a large proportion of the decomposition of litter. A raw humus rich in fine humus developed on the Iron-Humus Podzol, which was characterised by the activity of Oribatei and Diptera larvae. This varying composition of the soil fauna is also apparent when the traces of food in the various layers and soil horizons are analysed. In the Luvisol, which is influenced by a continental climate, the decomposition can be impaired by dry stress. On the other hand the lower nutrient supply influenced the decomposition processes in the Podzol.

Keywords: Orthic Luvisol, Haplic Podzol, litter, humus, soil fauna, decomposition, annual dynamic, moder, raw humus

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